

heat balance and the direction of the change in obliquity. It has been argued [2] that variations in the obliquity of Mars cause substantial departures from the current climatological values of the surface pressure and the amount of  $\text{CO}_2$  stored in both the planetary regolith and polar caps.

Haberle et al. [3] have constructed a heat balance model based on the work of Gierasch and Toon [4] that simulates the evolution of  $\text{CO}_2$  on Mars from the end of late heavy bombardment to the current time. The model partitions  $\text{CO}_2$  between its various reservoirs based upon predictions for polar, equatorial, and global-mean surface temperatures. The exchangeable reservoirs are atmosphere, planetary regolith, and polar caps. The model also loses  $\text{CO}_2$  irretrievably to a carbonate rock reservoir via aqueous chemical weathering according to the method of Pollack et al. [5]. The solar insolation is affected in time, however, only by varying solar luminosity; the relative distribution between equatorial and polar regions is invariant. Obliquity variation was avoided within the model by assuming that, throughout the 7.6-m.y. timestep, the current obliquity,  $\Theta = 25.2$ , sufficiently represents an average obliquity. It may be important, however, to explicitly study the climatological effects of obliquity variation since the size of the  $\text{CO}_2$  reservoirs can be significantly changed, drastically affecting the temperature structure through feedbacks from the greenhouse effect and the dynamic transfer of equatorial heat into polar regions.

In this new work we have modified the Haberle et al. model [3] to incorporate variable obliquity by allowing the polar and equatorial insolation to become functions of obliquity, which we assume to vary sinusoidally in time. As obliquity varies in the model, there can be discontinuities in the time evolution of the model equilibrium values for surface pressure, regolith, and polar cap storage. The time constant,  $\tau_r$ , for the regolith to find equilibrium with the climate is estimated [6], depending on the depth, thermal conductivity, and porosity of the regolith, between  $10^4$  and  $10^6$  yr. Thus, using 2000-yr timesteps to move smoothly through the 0.125-m.y. obliquity cycles, we have an atmosphere/regolith system that cannot be assumed in equilibrium. We have dealt with this problem by limiting the rate at which  $\text{CO}_2$  can move between the atmosphere and regolith, mimicking the diffusive nature and effects of the temperature and pressure waves, by setting the time rate of change of regolith storage proportional to the difference between equilibrium storage and current storage.

Model integration begins with the exchangeable reservoirs in equilibrium at mean obliquity. Starting at 3.5 G.y. ago with 1.0 bar of total available  $\text{CO}_2$ ,  $\tau_r = 10^4$  yr and  $10^\circ \leq \Theta \leq 50^\circ$ , the model initializes without polar caps. When obliquity decreases in a cycle, the annual polar insolation decreases causing the polar surface temperature to fall. This trend continues until  $\Theta = 23^\circ$  and the polar surface temperature reaches the frost point of the 180-mbar atmosphere, causing atmospheric collapse [3]. Such a collapse is estimated [6] to take  $10^2$  yr, well within our model timestep; thus, model pressure drops discontinuously to 0.5 mbar and reaches a minimum of 1.2  $\mu\text{bar}$  when  $\Theta = 10^\circ$ . The regolith responds, governed by  $\tau_r$ , freeing  $\text{CO}_2$ , which adds to the polar caps since atmospheric pressure is now buffered by the frost point relationship. When obliquity increases, model pressure and polar surface temperature increase until thermodynamic equilibrium can only be maintained at the polar surface after complete sublimation of the polar caps at  $\Theta = 42^\circ$ . Sublimation leaves a 500-mbar atmosphere, vs. 180 mbar at mean obliquity, causing 10 K and 20 K increases in respective global and

polar surface temperatures. Increased weathering is significant but short lived as the regolith finds equilibrium by quickly reducing atmospheric pressure. The obliquity peaks as the regolith nears equilibrium and the cycle repeats as obliquity begins to fall.

We find that including variable obliquity can cause our model to predict  $\text{CO}_2$  losses to carbonate formation of less than half that lost when obliquity is held constant at the mean. This is the case with the scenario described above, but preliminary experiments with different values of  $\tau_r$  have indicated that there is a complicated relationship between this parameter and the amount of  $\text{CO}_2$  lost to carbonates through an obliquity cycle. This relationship and the effect of a variable polar cap albedo are being studied.

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547-91 ABS. ONLY N94-33238 2  
**DIELECTRIC PROPERTIES OF MARS' SURFACE: PROPOSED MEASUREMENT ON A MARS LANDER.** S. Ulamec and R. Grand, Space Science Department of ESA, P.O. Box 299, 2200 AG Noordwijk, The Netherlands.

Recent studies of missions to Mars (MESUR by NASA and Marsnet by ESA) have suggested the development of semihard landers, also of considerably different designs. One type was to be extremely basic, consisting mainly of a meteorological package, but with the possibility of other small, low-mass, low-power instruments. In particular, this type of lander was also considered for the exploration of the polar regions.

Two methods to investigate the surface material at the landing site are discussed. Both measure the dielectric constant  $\epsilon$  of the ground material. This information can then be used to elucidate the surface composition and structure, and especially in the case of a landing on the polar ice, the determination of the permittivity would be of high scientific value.

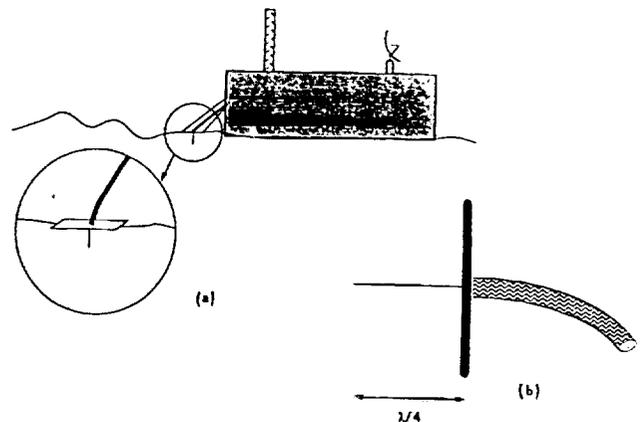


Fig. 1. (a) Possible arrangement of sensor on a Mars lander; (b) side view of suggested  $\lambda/4$  antenna.

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**N94-33239**

549-91 ABS ONLY

**CARBONATES, SURFATES, PHOSPHATES, NITRATES, AND ORGANIC MATERIALS: THEIR ASSOCIATION IN A MARTIAN METEORITE.** I. P. Wright<sup>1</sup>, M. M. Grady<sup>2</sup>, and C. T. Pillinger<sup>1</sup>, <sup>1</sup>Department of Earth Sciences, Open University, Walton Hall, Milton Keynes MK7 6AA, UK, <sup>2</sup>Natural History Museum, Cromwell Road, London SW7 5BD, UK.

The debate concerning the evolution of CO<sub>2</sub> on Mars continues. It would appear that in order to explain the valley networks and other relict fluvial landforms it is necessary to accept that liquid water was once present at the surface of Mars. This in turn requires, at some point in the planet's history, a higher surface temperature than exists today, a proposition explained traditionally by an early dense CO<sub>2</sub> atmosphere [e.g., 1]. However, there are a number of problems with this notion: for instance, CO<sub>2</sub> alone is not an efficient greenhouse gas because of its tendency to form clouds [2]. Moreover, if there was an early dense CO<sub>2</sub> atmosphere, it is necessary to explain where the elemental constituents now reside. There are two possibilities for the latter, namely loss to outer space of atmospheric CO<sub>2</sub> or the formation of vast carbonate deposits. While some models of atmospheric loss predict that up to 0.4 bar of CO<sub>2</sub> could be removed from the martian surface [3], this is still not enough to account for the original atmospheric inventory, usually considered to have been in the range of 1-5 bar. Thus, most models of the evolution of the martian surface require removal of CO<sub>2</sub> from the atmosphere and into carbonate deposits. However, as yet, the evidence for the existence of carbonates on Mars is fairly scant [e.g., 4]. This is an issue that would have been resolved by results obtained from Mars Observer.

While the existence of carbonates on Mars remains unsubstantiated, their presence in meteorites from Mars is undisputed. Furthermore, their origin as low-temperature secondary minerals, introduced at some point after the rock fabric of the meteorite had crystallized and cooled, has been demonstrated by isotopic measurements [5,6] and petrographic descriptions [7]. That the carbonate minerals are not simply weathering products produced on Earth has been demonstrated in one case by <sup>14</sup>C measurements, which show that there has not been an input of modern terrestrial C to the sample [8]. However, measurements from another sample show the presence of the <sup>14</sup>C isotope, interpreted as resulting from terrestrial contamination [9]. These results are somewhat unexpected since the <sup>12</sup>C/<sup>13</sup>C and <sup>16</sup>O/<sup>18</sup>O ratios of the carbonate minerals from the two different samples are similar [5,10]. At this point the exact significance of the <sup>14</sup>C data is unclear, but it would seem that in any particular sample there may be a few components containing <sup>14</sup>C that have been added from the terrestrial environment in addition to preterrestrial (i.e., martian) carbonates, characterized by the absence of <sup>14</sup>C. The presence of terrestrial contaminants in any meteorite sample is to be expected [5,11]; what is important is the use of analytical protocols that can effectively identify the components of interest. It is with challenges of this nature in mind that work continues with the study of weathering components in martian meteorites.

A particularly interesting sample is EET A79001, a meteorite collected from Antarctica. While rocks that experience Antarctic conditions may suffer from the effects of terrestrial inorganic weathering processes (e.g., the build-up on the outer surfaces of magnesium carbonate and bicarbonates, and hydrated magnesium and calcium sulfates), they are relatively free of organic contamination. Thus, it is interesting to note the association, deep within the meteorite, of carbonate minerals and organic compounds [12]. The carbonates are Mg-bearing and also contain P, i.e., there could be magnesium phosphates present [7]. Calcium sulfate, possibly gypsum, is also present [7], and there is also some tenuous evidence for the presence of nitrates [5,13]. On the basis of N isotope measurements it is clear that the nitrates could not have formed by a mechanism that utilized martian atmospheric N as a source material [5,13].

Because of the potential ramifications for martian surface evolution of the coexisting salts and organic compounds in EET A79001, it was perhaps inevitable that a further study of Antarctic weathering processes was necessary in order to constrain the possible extent of such effects. In this regard it is worth noting that EET A79001 has a weathering category "A" (i.e., only minor effects) and a fracturing category "A" (i.e., minor cracks). Since the meteorite is a single stone of mass 7.9 kg, measuring about 20 cm across, it is clear that samples from the center of the specimen ought to be predominantly free of the effects of terrestrial weathering. In contrast, a recently discovered martian meteorite from Antarctica, LEW 88516 (weathering A/B; fracturing A), weighs only 13.2 g and is less than 2 cm in size. Since the terrestrial ages of both Antarctic meteorites are similar, i.e., <50,000 yr, [14,15] it may be anticipated that the effects of weathering in LEW 88516 would be more severe than in EET A79001. However, LEW 88516 was found to contain the lowest C content of any of the nine known martian meteorites [16], even when material was taken specifically from the surface layers for analysis. This tends to support the notion that terrestrial weathering processes are not necessarily responsible for the components observed in EET A79001. A further consideration here arises from O isotope measurements of water released by heating, which, at face value, seem to demonstrate that EET A79001 has been affected to some degree by terrestrial weathering [17]. However, since it is now considered that the O isotope data should be treated with caution [8], their true significance, for the time being, remains poorly established.

So how do we explain the association of carbonates, sulfates, phosphates, nitrates, and organic materials in EET A79001? It has to be accepted that some of the inorganic minerals could have formed by terrestrial weathering processes. However, it is known for certain that martian meteorites, including EET A79001, contain preterrestrial weathering products [e.g., 7]. Furthermore, the associated organic compounds are present in higher abundances (i.e., by about 2 orders of magnitude) than can reasonably be expected for any contamination episode or handling procedures [12]. It would appear, therefore, that the coexistence of inorganic weathering products and organic materials in EET A79001 was established on Mars. In order to explain this phenomenon, perhaps attention should be turned to recent work that advocates an early CH<sub>4</sub>/CO<sub>2</sub> greenhouse on Mars [18], since this might ultimately lead to the formation of nonvolatile surface reservoirs of reduced and oxidized forms of C. An additional consideration, which could be pursued through chemical evolution modeling studies, infrared measurements of the